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A Review of Antenna Design for Millimeter Wave Range

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Abstract: *Due to great demand on data rate and bandwidth utilization in RF communication systems, recent research studies leads to the development of millimeter wave frequency range i.e. 30Ghz to 300 GHz. This paper focused on reviewing various millimeter wave antenna design and comparing the antenna parameter. These antennas were designed using various simulators such as HFSS, ADS and CST.*
Keywords: *Millimeter wave spectrum, antenna, and 5G technology*.

I. Introduction

In order to handle the high traffic rate, scarcity of bandwidth and quality of service millimeter wave frequency is evolved for 5G applications. The Internet connection provided by 5G is 40times faster than the 4G technology. The greatest advantage of millimeter wave is that it can transmit large amount of data. More than five billion devices demand wireless connections that run voice, data, and other applications in today's wire-less networks. Enhancing the limits of the system with better coverage at low cost is the primary goal of the 5G. The most essential and exceptionally basic target of all is the "capacity" as it straightforwardly identifies with the developing client interest for speedier and higher information rates. For future millimeter wave communication systems, world radio communication conference 2015 had been identified frequency allocation from 24 to 86GHz [1].Due to light, compact and integrated into module circuit, microstrip antenna is essential for supporting mobile terminal of wireless communication systems. Current trends lead to the development of antenna which will transmit and receive the wideband characteristics and high gain that can be operate in frequency range from 24GHz to 100GHz.Millimeter waves are the very high frequency waves but they can be transmitted over short distance of communication since the wavelength ranges from 10mm to 1mm [2].The wavelength is inversely proportional to frequency. So the increasing frequency makes the wavelength to decrease. The Millimeter waves offers high speed point to point communication and provides data rate up to 1Gbps, these can be used for variety of services in wireless systems especially in telecommunication.

The microstrip patch antenna finds numerous applications in modern wireless systems[2].This microstrip patch antenna makes the high standard of data transfer and makes the fabrication simple with low cost, it can make the millimeter wave suitable for commercial purpose. The Wi-Fi and WiGig standard IEEE802.11ad has been supervised by 60GHz band. The devices can communicate without the use of wire at multi gigabit rate by using the WiGig standard. The 59-64 bands has been allocated as the unlicensed band by the Federal communication commission in which the frequency is suitable for short range and high speed wireless communication [3].The characteristics of millimeter wave band is that the path loss increases when the frequency of operation increases correspondingly the signal wavelength decreases which is proposed by Friss transmission equation [4].By taking patch antennas of smaller and uniform dimension that can be arranged in array structure, the path loss effects can be reduced and it is the suitable for millimeter wave applications. In addition to this, this array structure can improve the gain of the systems. since the array consumes less power, the overall cost can be reduced[4].The millimeter wave frequencies will be widely used by fifth generation wireless communication networks[5].

The atmosphere absorbs the millimeter wave there is severe propagation loss in the antenna designed for millimeter wave frequency [6] [13] 14]. These millimeter waves' antennas are in smaller and compact in size that can be fit into the handheld devices. Slotting, grounding and material properties were the several optimization techniques that can be used in the antenna design. Since the Leaky Wave Antenna have low profile they have received more attention millimeter wave applications.

II. Literature Review

A. Millimeter wave a new gridded parasitic patch stacked micro strip antenna.

This antenna consists of three layer substrates. At the bottom named as layer1 is used for feeding micro strip line electromagnetically coupled to the patch and two slots under it. At the middle named as layer 2 is used as radiating element with rectangular patch shape for gain the radiating electromagnetically to the nine gridded patches at the top layer 3. There are nine patches to reach the maximal bandwidth in the layer 3. The length P is about 10 mm and width L is about 5 mm. Taconic TLY with 0.127 mm thickness and 2.2 constant dielectricum has been used as the substrate. 5.984 is the feeding line main length named as Ws and line width s of 0.375(= 50 Ohm). In the side of fork like tuning stubs are consist ofU1 = 1.4 mm, U2 = 1.125 mm and U3 = 0.375 mm. To reach optimum matching impedance the multituning stubs are adjusted in order to give enhanced bandwidth [1].

In this design bandwidth obtained is about 15.6 GHz and the return loss of -10 dB with the frequency range from 49.6 GHz to 65.2 GHz. For frequency 60GHz the VSWR value is 1.06. At frequency 43.2 the gain obtained is about 9.3dB and at the frequency 60GHz the gain value is 8.4dB.

B. Millimeter wave double F slot patch antenna.

This antenna is designed by using silicon as a substrate material having dielectric constant of about 11.9. Double F slot patch width is about 0.9843mm and length is about 0.62mm. The lengths of F slots are L1 is 0.25, L2 is 0.2, L3 is 0.1 and the widths are about W1 is 0.025, W2 is 0.02, W3 is 0.02. The efficiency and impedance matching of the antenna can be improved by adding slots [2].

In this design the return loss obtained is about -32.5dB with the frequency range of 58.10GHz. The directivity and efficiency of the antenna is about 7.55dB and 69.83. At frequency 58.10GHz the gain value is 5.99dB.

C. Millimeter wave single band microstrip patch antenna.

This antenna contains the dimension of about 8mm x 8mm and it uses Rogers RT5880 as a dielectric material having the permittivity of 2.2, loss tangent 0.0009 and height 1.6mm. In order to improve the impedance bandwidth there is H and E slot cut on the patch [3].The main radiating element is patch. The length of patch is about 3.5mm ad width is 2.9mm. The length of the H slot is about 2.4mm and width is 2.5mm. The length of E slot is about 1.5mm and width is 1.35mm. The length of the feed line is about 0.4mm and the width is 3.25mm.

In this design the bandwidth obtained is about 4.028GHz with center frequency at 59.93GHz. The VSWR value obtained is less than 2 which will provide the good impedance matching [3]. The gain value obtained is about 5.48dB. The return loss is -42dB.

D. Millimeter wave 16 Element array of microstrip patch antenna.

This antenna is designed with the dimension of about 34.265mm x 34.265mm which uses RT duroid as the dielectric material having the permittivity of about 2.2 and height is about 0.25mm. The single antenna patch contains the same length and width of about 3.47mm. The 2 x 2 array is formed by arranging four patches in geometrical shape of square by using connectors having same length and width. Then by connecting four similar 2 x 2 arrays the 16 element array can be obtained. The excitation is provided by using the co-axial feed. Instead of using micro-strip feed lines the co-axial feed lines are used to in order to eliminate the spurious radiation inside the substrate [4]. When the width of the feed line is 0.5mm the operating frequency obtained is 28.5GHz and when it is 0.25mm the frequency obtained is 33 GHz. Thus by changing the width of feed lines, the operating frequency can also be changed [4].

In this design when the operating frequency is 28.5GHz the gain obtained is about 14.82dB and when the frequency is 33GHz the gain value is 10.09dB. The corresponding return loss for these two frequencies are -21.7dB and -26dB.The bandwidth obtained is about 112.6MHz and 1212.1MHz.

E. Millimeter wave dual-band printed slot antenna.

This antenna is designed with the dimension of about 8mm x 7.5mm which uses RoggersRT5880 as a dielectric material having dielectric constant of about 2.2 and thickness 0.127mm. The patch is in the shape of sector disk having radius of 1.5mm placed non-concentrically inside a circular shaped slot having radius of about 3mm which is then etched on the ground plane structure. The 50- ohm proximity microstrip feed line having width and length of 2.42mm and 0.8mm is used to excite the patch. In order to provide better impedance matching, the stub having width and length of 0.85mm and 0.29mm is connected in shunt manner [5]. The rectangular slots of width and length 0.5mm and 0.28 are etched on the ground plane in order to improve the gain and radiation efficiency [5].

This antenna design can cover the dual band 28GHz and 38GHz.The corresponding return loss for these two bands are -20.2dB and -30.8dB. The gain value obtained for 28GHz operating frequency is 4.2dB and for 38GHz is about 6.9dB.

F. Millimeter wave pharaonic ankh-key broadband antenna.

This antenna is designed with the dimension of about 7.5mm x 7.5mm which used RoggersRT5880 as a dielectric material having dielectric constant of about 2.2. In this design the patch is in the shape of pharaonic ankh-key. The patch is having the dimension of about 4mm x 3.9875mm. Here the patch is excited by using the 50 ohm microstrip feed line. The height h=0.508mm is used for designing the patch from the rectangular ground plane [6].

In this design the return loss obtained is about -20.2dB. The operating frequency for this antenna is 60.5-72GHz.The gain value obtained for this antenna is about 8.4dB. The VSWR value is less than 2.

G. Millimeter wave magnetoelectric dipole leaky-wave antenna.

This antenna design consists of two-layer substrate. The first layer uses RoggersRT5880 as a dielectric material having dielectric constant 2.2 and thickness of about 1. 57mm.It consists of SIW-fed longitudinal shunt slot antenna array. The second layer uses RoggersRT5880 as a dielectric material with a thickness of about 0.787mm. It consists of 18 pairs of planar electric dipoles. The metal via side walls are formed in SIW layer.1.5mm and 0.9mm are the separation between adjacent via and diameter of each particular via. In order to restrict the power leakage, the separation distance of the via will be very small [7]. The longitudinal shunt slot antenna array becomes a leaky-wave ME dipole antenna due to the presence of electric dipoles [7].

In this design the operating frequency obtained is 28 to 32GHz.The corresponding gain of this antenna is 16.55dB and the corresponding return loss is -25 dB. The VSWR for this antenna is 1.076. For smoothing the gain within the pattern bandwidth an electric dipole is added on each slot of LWA [7].

H. Millimeter wave dual band antenna.

This antenna is designed with the dimension of about 4.9mm x 7.6mm which uses RoggersRT5880 as a dielectric material having the dielectric constant 2.2 with thickness of about 0.127mm. The frequency drop of the antenna can be improved by tuning the size of feed line [8].

In this design the operating frequency obtained is 24.25GHz and 38GHz.The corresponding gains for these dual bands are 5.5dB and 4.5dB respectively. The return loss for these antennas is -40dB.The VSWR value is less than 2.

I. Millimeter wave dual-polarized patch array antenna.

This antenna is designed with the dimension of about 11.6mm x 11.6mm. Here the four patch antennas are arranged in array structure. When the frequency is increased, the dielectric constant of FR4 get decreases [9]. The package substrate is used for this antenna design and this antenna package should constitute a SiP for 5G communication systems.

In this design the operating frequency achieved is 28.5GHz. The gain of the antenna array is 10dB.The corresponding return loss is about -20dB and VSWR is 1.098. The 1.5 to 2GHz bandwidth is achieved when the height of the dielectric material is high [9].

J. Millimeter wave printed patch antenna array.

This antenna is designed with the dimension of about 30.25mm x 9.5mm which uses RoggersRT5880 as a dielectric material having 2.2 as the dielectric constant with thickness of about 0.508mm. The feeding mechanism used for these antenna is 50 Ω Sub Miniature Version A (SMA) connector. The spacing between the patch is about 3.54mm. In order to obtain the same phase the length of transmission line of the middle patch antenna is set to be equal with the adjacent patch to make the same phase [10].

In this design the operating frequency obtained is about 37GHz.The gain value achieved by this antenna is about 13.8dB. The return loss for this antenna is -17dB and VSWR is less than 2. When the patch is arranged in array structure, the gain of microstrip patch antenna get increased due to the increasing aperture area and efficiency of the antenna [10].

k. Millimeter wave planar antenna.

This antenna is designed by using PET as a substrate material.PET (polyethylene terepthalate) films have varying permittivity and loss tangent gives the advantages of low cost, high flexibility, harmless to human body and resistive towards human body [11]. This PET substrate contains dielectric constant of about 3.2 and the loss tangent is 0.022.T-shaped patch given with coplanar waveguide feeding and an aperture in ground plane is printed by using the PET substrate. In the left and right side of the patch antenna, the resonating slots each of width 2mm placed 5mm distance apart are the introduced. The multiple resonating bands are obtained by using these slots [11].

In this design the operating frequency obtained is 22-40GHz and the gain value id above 4dB.At frequency 38.75GHz the peak gain value obtained is about 8.2dB. The return loss for these antenna is about -18dB and VSWR is less than 2.

L. Millimeter wave microstrip antenna array.

This antenna is designed with the dimension of about 2.5mm x 2.25mm having RoggersRT5880 having the permittivity of 2.2 as a dielectric material with thickness 15mil.The array structure is formed by using 64 element microstrip patch antenna.RF section of multiple input multiple output system is formed by introducing 64 T/R modules[12].To obtain a beam scanning angle of 30 degree azimuth, the array element spacing are arranged in triangular lattice.

In this design the operating frequency obtained is about 38GHz.The return loss for this antenna is about -40dB and corresponding gain value obtained is 8dB.The VSWR value is less than 2.

M. Millimeter wave patch antenna array.

The performance of the substrate becomes more critical when the operating frequency get increases [13]. The antenna is designed with the dimension of about 55x70 mils which uses Liquid crystal polymer (LCP) as a substrate having the dielectric constant of 2.9 and loss tangent of about 0.0025. The gap between the feed line and patch is 3.2 mil in order to make the coupling effect small. In the microstrip structure most of the electric field line propagates into the substrate and some of them exist in air. Hence the effective dielectric constant of about 2.44 is used for the account of fringing. Due to the effect of fringing the microstrip patch antenna looks electrically larger than its physical dimension [13]. This structure supports the transverse magnetic propagation mode. Here microstrip corporate feed network is used.

For 4x4 array antenna design the gain value obtained is 16.7dB and the corresponding beam width and efficiency is 24 degree and 64 respectively. For 8x8 array antenna design the gain value is 17.1dB and the corresponding beam width and efficiency is 11 degree and 24 respectively. The return loss for the 4x4 and 8x8 array antenna is about -20 dB.The operating frequency obtained for this antenna design is about 57 to 64GHz respectively. The power can be distributed to each individual patch by using the quarter wave T junction power divider [13].

N. Millimeter wave dense dielectric patch array antenna.

This antenna is designed by using the DD patch radiator elements fed by 1 to 4 Wilkinson power divider. The array radiation characteristics can be optimized by using the ground structure based on the compact uniplanar electromagnetic band gap unit cell [14]. A dielectric layer of a superstrate is applied above the antenna array. This antenna structure uses RoggersRT5880 as a dielectric material having the dielectric constant of about 2.2 and the loss tangent is 0. 0009.It contains two substrate having same length, width and height.

In this design the operating frequency obtained is about 28GHz.The bandwidth for the corresponding antenna is about 27.1 -29. 5GHz.The gain value obtained is 12.48dB and the total efficiency of this antenna is about 91.9%. The return loss for this antenna is about -29dB.The losses produced due to surface waves can be reduced by using the electromagnetic band gap structure(EBG)[14].

0. Millimeter wave pattern reconfigurable antenna.

This antenna consists of two layers which is of planar structure. It uses the RoggersRT5880 as a dielectric material having the dielectric constant 2.2.1x4 power divider integrated with RF switches can be used in this design. The RF switches are positioned at half wavelength away from the feed at the center. Due to the off state of the switch, the input impedance of the path become open circuited [15]. Three quasi-Yagi antennas and one patch antenna were used in the multi antenna structure.

In this design the operating frequency obtained is about 36-40GHz.The maximum gain obtained is about 8dB and corresponding return loss is about -10dB.The VSWR value is less than 2. From these design it is clear that patch has higher gain than the quasi yagi[15].

III. Comparative Analysis Of Different Antenna Design For Millimeter Wave Range

Different types of antennas designed for millimeter wave range are analyzed based on the type of antenna and also the material used for the antenna design. The basic parameters for the antenna design such gain, return loss and VSWR are also have been analyzed. The operating frequency in which antenna resonate have also been analyzed.The entire analysis haven been tabulated in the table 1.

Table 1. Comparitive Analysis Of Different Antenna Design For Millimeter Wave

Paper	Type of antenna	Material for design	Operating frequency (GHZ)	Gain (dB)	Return loss (dB)
6	Pharaonic ankh-key broadband antenna.	RT Duroid	60.5-72	8.4	-20.2
1	New gridded parasitic patch stacked micro strip antenna.	Taconic TLY	60	8.4	-10
13	Patch antenna array	Liquid Crystal Polymer	57	16.7	-20
			64	17.1	-20
3	Single band microstrip patch antenna.	RT Duroid	59.93	5.4	-42
2	Double F slot patch antenna.	Silicon	58.10	5.99	-32.5
15	Pattern reconfigurable antenna.	RT Duroid	36-40	8	-10
11	Planar antenna.	PET	22-40	8.2	-18
12	Microstrip antenna array	RT Duroid	38	8	-40
5	Dual-band printed slot antenna.	RT Duroid	28	4.2	-20.2
			38	6.9	-30.8
8	Dual band antenna.	RT Duroid	24.25	5.5	-40
			38	4.5	
10	Printed patch antenna array.	RT Duroid	37	13.8	-17
4	16 Element array of microstrip patch antenna	RT Duroid	28.5	14.82	-21.7
			33	10.09	-26
7	Magnetoelectric dipole leaky-wave antenna.	RT Duroid	28-32	16.55	-25
9	Dual-polarized patch array antenna.	FR4	28.5	10	-20
14	Dense dielectric patch array antenna.	RT Duroid	28	12.48	-29

IV. Conclusion

In this survey, design of various antennas for millimeter wave range has been discussed. These antennas can find applications in radio broadcast, TV, 5G cellular mobile communications. These antennas can be simulated by using various software like HFSS, CST and ADS. Among the several antenna designs the Pharaonic Ankh-key broadband antenna gives the better operating frequency suitable for 5G networks as well as high gain.

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